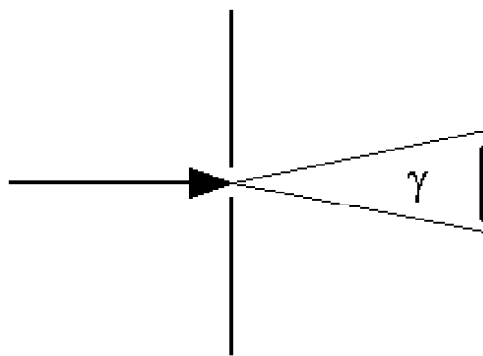26. Monochromatic light of wavelength 550 nm from a distant source is incident normally on a slit 0.80 mm wide. A diffraction pattern of bright and dark fringes is viewed on a screen 5.0 m away from the slit. The **angular** width γ of the central maximum, as shown in the figure, is ... (in seconds of arc):

(A) 142

(B) **284**

(C) 709

(D) 1418

(E) 0.00788

Hint: $1°=3600"$. 1 degree equals 3600 seconds of arc.

27. A discharge tube contains a gas which produces three strong emission lines having different wavelengths λ_1, λ_2, λ_3. The radiation from this lamp is incident on series of slits. The interference pattern produced by the slits is projected on a screen as shown in the figure. Which of the possible combinations of colors would be viewed by an observer, assuming that all wavelengths are observed in first order ?

(A) $(\lambda_1, \lambda_2, \lambda_3)$ is (red, yellow, blue)

(B) $(\lambda_1, \lambda_2, \lambda_3)$ is (yellow, red, blue)

(C) $(\lambda_1, \lambda_2, \lambda_3)$ is (blue, red, yellow)

(D) $(\lambda_1, \lambda_2, \lambda_3)$ **is (blue, yellow, red)**

(E) None of these are correct.
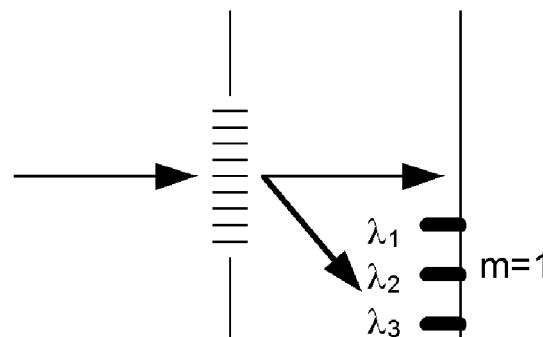
28. A thin coating of a material ($n=1.25$) is used to coat a camera lens ($n=1.5$). For the minimum amount of reflected light (at nearly normal incidence) at wavelength λ_0 to occur, the minimum thickness of the film must be (Note: λ_0 represents the wavelength of light in **vacuum**):

(A) $\lambda_0/\mathbf{5}$

(B) $\lambda_0/4$

(C) $\lambda_0/2$

(D) $\lambda_0/3$

(E) $\lambda_0/6$
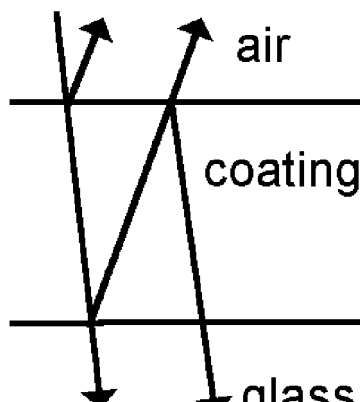
29. Which of the following statements about Young's double slit experiment is **true** ?

   (A) If the spacing between the slits is increased, then the interference pattern becomes wider (spreads out).

   (B) **If the double-slit experiment is done under water, then the distance between the bright fringes decreases.**

   (C) If monochromatic light is incident on two slits, there will always be a noticeable interference pattern, regardless of the slit-separation distance.

   (D) An interference pattern can be observed with a light beam, but not with a beam of protons.

   (E) None of the above statements are true.

30. Unpolarized light is incident on the series of polarizers as shown. The transmission axis of the first polarizer makes an angle of $60°$ with the z-axis. The second polarizer is aligned with its transmission axis along the z axis. What is the fraction of the average intensity of the incident light transmitted through this combination?

   (A) 0.866

   (B) 0.5

   (C) 0.25

   (D) 0.0625

   (E) **0.125**
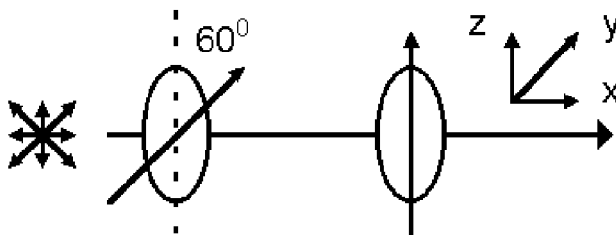
31. In making a transition from an $n=2$ to an $n=4$ state, a hydrogen atom

   (A) emits a photon of energy 13.6 eV.

   (B) absorbs a photon of energy 13.6 eV.

   (C) emits a photon of energy 2.6 eV.

   (D) **absorbs a photon of energy 2.6 eV.**

   (E) This transition is forbidden.

32. Estimate the radius of a germanium atom (32 electrons, 32 protons, 40 neutrons) using the Bohr model. Hint: The periodic table of the elements shows that the first three Bohr shells are filled, the fourth one is half-filled. A valence electron in the outer (fourth) shell sees a positive core with a net charge of $4|e|$. Note that 1 Å=0.1 nm.

   (A) 0.53 Å

   (B) **2.12 Å**

   (C) 8.48 Å

   (D) 0.27 Å

   (E) 0.13 Å

33. The Celsius and Fahrenheit temperature systems agree in the

(A) size of their degree.

(B) location of their $-20°$ points.

(C) location of their zero points.

(D) **location of their $-40°$ points.**

(E) numerical value at the boiling point of nitrogen.

34. A container can hold one mole of oxygen (with a molecular mass of 32 g/mol) when filled at room temperature (27°C) and atmospheric pressure (101.3 kPa). The volume of the container is

(A) **24.6 L**

(B) 22.4 L

(C) 27 L

(D) 30.5 L

(E) 3.05 L

35. One mole of germanium (a silvery, hard solid) is shaped into a cube of side 37.9 mm at atmospheric pressure and room temperature. The bulk modulus of germanium is 75 GPa. Somewhere deep inside the earth, where the pressure is 10 GPa (100 kbar), the side of the cube is

(A) 39.7 mm

(B) 34.3 mm

(C) **36.1 mm**

(D) 37.9 mm

(E) 32.9 mm

36. A cube of wood with side of 1 m weighs 600 kg. Find the fraction of wood **above** the surface of water (fresh water at 4° C). Hint: Assume that there are no waves on the surface and that the wood is not accelerated.

(A) 20%

(B) **40%**

(C) 60%

(D) 80%

(E) None of the above.

Physics 222: Solutions for Written Problems in Exam #3

Problem 1:

Light from a quartz-tungsten-halogen lamp (which we treat as a source of blackbody radiation) is incident (almost) normally on the surface of a soap bubble (with refractive index $n=1.28$) that is $t=200.0$ nm thick. See figure for parts C., D., and E.
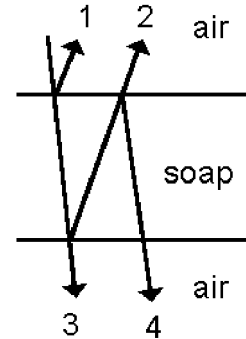
A. What are the general conditions for the phase difference between two waves for (1) constructive and (2) destructive interference (1 point) ?

Answer: (1) Two waves interfere constructively if their phase difference is an integral multiple of 2π. (2) They interfere destructively if their phase difference is an odd multiple of π.

B. What do you know **in general** about phase changes at interfaces between media with different refractive indices for transmitted or reflected beams (2 points)?

Answer: (1) The transmitted beam does not experience a phase shift at an interface. (2) The reflected beam does not have a phase shift, if the beam encounters a medium with a lower refractive index (high to low, phase change no). (3) If the refractive index of the encountered medium is larger than that of the original medium, there is a phase shift of π or $180°$.

C. Now refer to the figure and determine expressions for the total phase difference between beams (1) and (2) and between beams (3) and (4). Assume normal incidence (2 points).

Solution: Beam (1) experiences a π phase shift at the air/soap interface. Beam (3) is a transmitted beam, therefore there is no phase shift. Beams (2) and (4) are reflected at soap/air interfaces, therefore they do not have a phase shift due to reflection.
Including the phase shift due to the path difference $\delta = 2d$, the phase difference between beams (1) and (2) is $\phi_{12} = \pi + 4n\pi t/\lambda$, where λ is the wavelength in vacuum (or air). The phase shift between beams (3) and (4) is $\phi_{34} = 0 + 4n\pi t/\lambda$.

D. For what wavelength(s) of **visible** light will the intensity of the **reflected** light be a minimum (2 points) ?

Solution: For destructive interference, the phase shift ϕ_{12} needs to be an odd multiple of π: $\phi_{12} = \pi + 4n\pi t/\lambda = m\pi$. Therefore, $1 + 4nt/\lambda$ needs to be odd, $4nt/\lambda$ needs to be even. This implies that $2nt=512$ nm needs to be an integral multiple of λ. The visible range of the spectrum includes wavelengths between 400 and 700 nm. $\lambda=512$ nm (green-blue) is the only multiple of 512 nm in this range. $\lambda=256$ nm is considered UV.

E. For what wavelength(s) of **visible** light will the intensity of **transmitted** light be a maximum ? For what filament temperature T will the lamp have its maximum spectral energy density at this wavelength (3 points) ?

Solution: The phase shift $\phi_{34} = 4n\pi t/\lambda$ needs to be a multiple of 2π, therefore $2nt$=512 nm needs to be a multiple of the wavelength. As above, the only visible wavelength meeting this condition is λ=512 nm. (1 point)

According to Wien's displacement law, the maximum spectral energy density occurs for $\lambda_{\max}T$=2.898×10^{-3} Km. $\lambda_{\max}$=512 nm, if T=5660 K (2 points).

Problem 2:

A certain metal was used to demonstrate the photoelectric effect. The experimental setup is shown on the right. The results of the experiment are shown on the left.
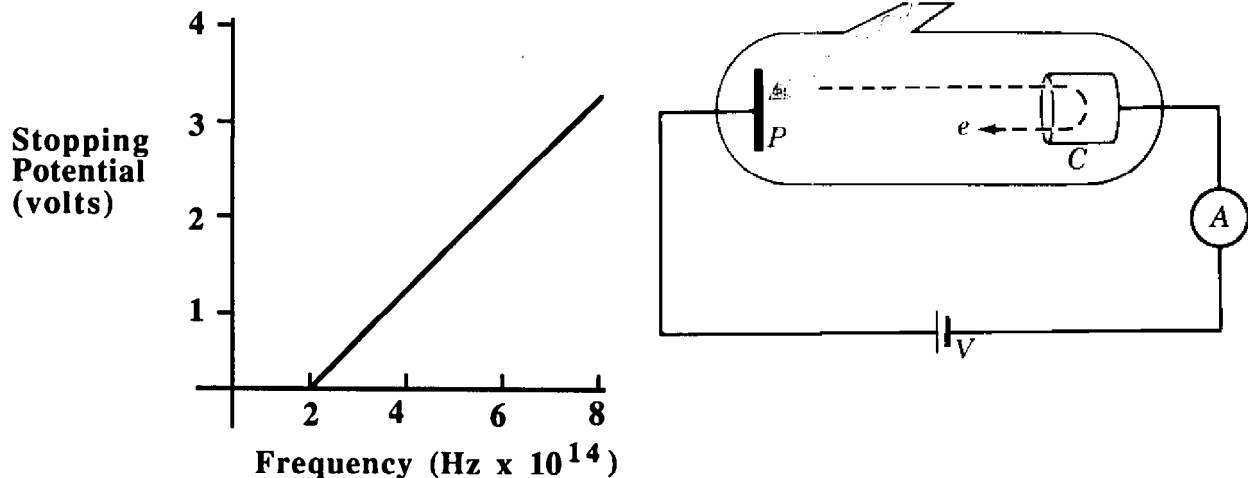
A. Describe in words why the stopping potential increases when the frequency of the light increases. Use complete sentences (3 points).

Answer: With increasing frequency, the energy of the incident photons increases. Therefore, the most energetic electrons kicked out of the material have a higher kinetic energy. Therefore, they can overcome a larger bias voltage (stopping potential).

B. Determine the work function (in eV) of the material (2 points).

Solution: The workfunction ϕ is given by $\phi = h f_0$=0.83 eV.

C. If a monochromatic source of wavelength 500 nm is incident upon the metal, what energy will the most energetic electrons escaping from the surface have ? (3 points)

Solution: The energy of the photons at 500 nm is $E = hc/\lambda$=2.48 eV. The energy of the most energetic electrons is (2.48−0.83) eV=1.65 eV.

D. What is the de Broglie wavelength of an electron emitted with a kinetic energy of 3 eV ? (2 points)

Solution: The velocity of such an electron is $v = \sqrt{2K/m}$=1.03×10^6 m/s. Its de Broglie wavelength is therefore $\lambda = h/(mv)$=7.06 Å.

Problem 3:

Water flows through a horizontal pipe with circular cross-section and is delivered into the atmosphere at a speed of v_1=15 m/s as shown in the figure. The diameters of the straight sections of the pipe are d_2=5.0 cm on the left and d_1=3.0 cm on the right.
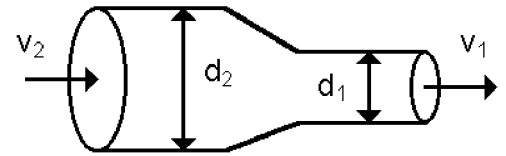
A. What volume of water is delivered into the atmosphere during a 10 minute period ? (2 points)

Solution: The volume flowing out of the pipe in 10 minutes (600 s) is given by

$$V = (d_1/2)^2 \pi v_1 \Delta t = (0.015 \text{ m})^2 \times \pi \times 15 \text{ m/s} \times 600 \text{ s} = 6.36 \text{ m}^3.$$

B. What is the flow speed v_2 of the water in the straight section of the pipe on the left ? (2 points)

Solution: For laminar flow with an incompressible fluid, we have $A_1 v_1 = A_2 v_2$ (continuity equation). Therefore,
$$\pi (d_1/2)^2 v_1 = \pi (d_2/2)^2 v_2.$$
This implies that $v_2 = v_1 (d_1/d_2)^2$=5.4 m/s.

C. What is the gauge pressure in the straight section of the pipe on the left ? (4 points)

Solution: We use Bernoulli's equation requiring $P + \rho g y + \frac{1}{2}\rho v^2$ to be constant. Since y=0, the second term vanishes. In the right section of the pipe (where the water emerges into the atmosphere), the pressure is P_1=1 bar. Therefore, $P_1 + \frac{1}{2}\rho v_1^2$=2.125 bar. In the straight section on the left, the pressure is P_2=2.125 bar$-\frac{1}{2}\rho v_2^2$=1.98 bar. (1 bar=10^5 Pa.)
The gauge pressure is determined by subtracting the atmospheric pressure (1.01 bar). The gauge pressure is therefore 0.97 bar=97 kPa.

D. How do we call the type of motion assumed in this problem? What are the conditions and characteristics for this type of motion? Answer in complete sentences (2 points).

Answer: We assumed that we have **laminar flow** to solve this problem. Laminar flow requires a **nonviscuous** fluid (no friction) and assumes that the flow is **steady** (constant pressure and velocity, Laplace's principle) and that it does not have **curls** (irrotational flow). We also had to assume that the fluid is **incompressible**.